

EA417  
FLIGHT TEST IA

Airspeed and Altimeter  
Position Error Calibration

## I. Purpose

To determine the airspeed and altimeter system error (position error) in the test aircraft.

## II. References

1. McCue, J.J., "Pitot-Static systems, Naval Test Pilot School
2. Hurt, "Aerodynamics for Naval Aviators," pp. 1–14
3. [http://web.usna.navy.mil/~dfr/technical\\_flying.html](http://web.usna.navy.mil/~dfr/technical_flying.html)
4. [http://web.usna.navy.mil/~dfr/aircalw\\_web.pdf](http://web.usna.navy.mil/~dfr/aircalw_web.pdf)
5. [http://web.usna.navy.mil/~dfr/airspeed\\_wide.pdf](http://web.usna.navy.mil/~dfr/airspeed_wide.pdf)
6. <http://web.usna.navy.mil/~dfr/horseshoehead.pdf>
7. <http://web.usna.navy.mil/~dfr/flttst.html>
8. Class notes

## III. Background and Theory

### Airspeed Indicator

The true airspeed (the speed of an aircraft through the surrounding air mass) is important in determining aircraft performance and stability and control. Unfortunately, true airspeed usually cannot be read directly from a cockpit instrument because of the technique used to calibrate the airspeed indicator as well as several sources of error.

Four airspeed definitions are used when considering these errors. They are:

- IAS: *indicated airspeed* is the value read on the indicator.
- CAS: *calibrated airspeed* is indicated airspeed corrected for instrument errors (gauge error) and errors due to position or location of the pitot and static pressure taps (position error).
- EAS: *equivalent airspeed* is calibrated airspeed corrected for compressibility effects.
- TAS or V: *true airspeed* is equivalent airspeed corrected for nonstandard density effects (other than compressibility).

For purposes of this investigation, the static source position error is assumed to be the major source of airspeed and altimeter system error, i.e., gauge error, compressibility effects and pitot probe errors are assumed negligible. The correction for nonstandard density is applied.

Because the static source for both the airspeed indicator and the altimeter is the same, the position error of each of these instruments is the same. In this test we determine airspeed indicator position error and then convert airspeed error (kts) to altimeter error (ft).

### OAT Gauge

The outside air temperature gauge, designed to measure static temperature, is subject to both gauge error and compressibility error. We assume that the OAT gauge has no inherent gauge error. At low speeds, compressibility effects are also negligible.

### Reference Weight

In flight, weight is constantly changing due to fuel consumption. For meaningful analysis, test data must be converted to equivalent data at an aircraft standard or reference weight. The reference weight is the maximum gross weight of the aircraft.

## Airspeed Calibration

### *Classical Technique*

The classical technique for calibrating the airspeed indicator is to fly the aircraft on a constant heading (and its reciprocal) at a constant altitude and airspeed between two geographic positions a known distance apart. The true airspeed is then obtained from the two runs as follows:

on the initial leg

$$\text{TAS} + \text{WS} = \frac{d}{t_1}$$

and on the reciprocal leg

$$\text{TAS} - \text{WS} = \frac{d}{t_2}$$

where TAS = true airspeed, WS = headwind or tailwind component,  $t_1$  = the time to traverse the course on the outbound leg and  $t_2$  = time to traverse the course on the inbound leg. Adding these two expressions yields

$$2(\text{TAS}) = \frac{d}{t_1} + \frac{d}{t_2}$$

Rearranging we have

$$\text{TAS} = \frac{d}{2} \left( \frac{1}{t_1} + \frac{1}{t_2} \right) \quad (1)$$

Assuming a constant value for any crosswind, then the crosswind component need not be considered because a constant heading is flown until directly abeam of the second geographical checkpoint. Thus, even though we traverse more than the distance  $d$  over the ground, the distance flown through the air mass is exactly  $d$ . (see Ref. 4 for additional details.) Although, when carefully performed, the classical technique yields good results, in practice, good results are difficult to obtain because the aircraft must be flown at low altitude where air turbulence may be a significant factor.

Other classical airspeed calibration techniques include the tower flyby, trailing cone or bomb and using a pacer aircraft with a previously calibrated airspeed indicator (see Ref. 1 for details).

### *GPS*

Using GPS for airspeed calibration has considerable appeal. However, GPS provides ground speed and ground track and not speed through the air. As shown in Ref. 4 direct extension of the classical technique in which a constant GPS track and its reciprocal are flown, can lead to significant errors. A number of airspeed calibration techniques using GPS or Differential GPS (DGPS) have been proposed. The most attractive of these, called the horseshoe heading technique, has its roots in the kitbuilt/experimental aircraft community (see Ref. 6 for more details).

### *Horseshoe Heading Technique*

The horseshoe heading technique uses the GPS ground speed from three successive constant heading constant altitude legs at successive 90° headings from each other to eliminate the effects of wind (see Figure 1). The method can be used at any reasonable altitude.

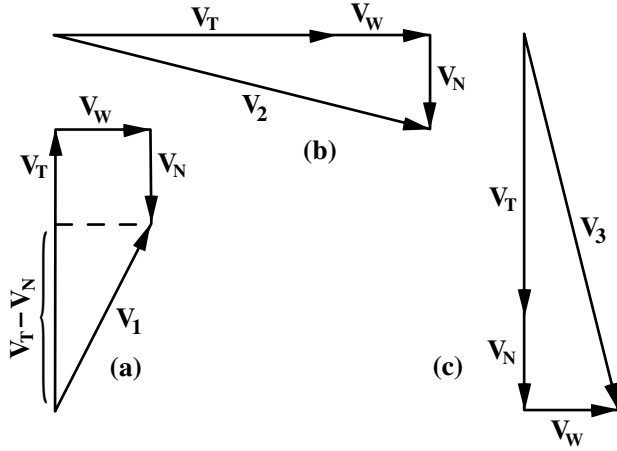


Figure 1. Horseshoe heading technique.

From Figure 1 parts (a), (b) and (c), respectively, the three equations in the three unknowns  $V_T$ ,  $V_N$  and  $V_W$  are

$$(V_T - V_N)^2 + V_W^2 = V_1^2 \quad (2)$$

$$(V_T + V_W)^2 + V_N^2 = V_2^2 \quad (3)$$

$$(V_T + V_N)^2 + V_W^2 = V_3^2 \quad (4)$$

where  $V_T$ ,  $V_N$ , and  $V_W$  are the true airspeed and northerly and westerly components of the wind, respectively.  $V_1$ ,  $V_2$ ,  $V_3$  are the three measured GPS ground speeds for the three successive headings. Expanding and adding Eqs. (2 and 4) yields

$$2V_T^2 + 2V_N^2 + 2V_W^2 = V_1^2 + V_3^2 = P \quad (5)$$

Similarly, expanding and subtracting Eq. (4) from Eq. (3) yields

$$-2V_TV_N + 2V_TV_W = V_2^2 - V_3^2 = Q \quad (6)$$

Finally, subtracting Eq. (4) from Eq. (2) yields

$$-4V_TV_N = V_1^2 - V_3^2 = R \quad (7)$$

$V_1$ ,  $V_2$  and  $V_3$  are the known GPS ground speeds. Hence,  $P$ ,  $Q$  and  $R$  are known; and Eqs. (5, 6 and 7) represent three equations in the three unknowns,  $V_W$ ,  $V_N$  and  $V_T$ . Solving Eq. (7)

$$V_TV_N = -\frac{R}{4} \quad (8)$$

Substituting Eq. (8) into Eq. (6) yields

$$2V_TV_W = Q - \frac{R}{2}$$

or

$$V_W = \frac{2Q - R}{4V_T} \quad (9)$$

From Eq. (8)

$$V_N = \frac{-R}{4V_T} \quad (10)$$

Provided the true airspeed is available, the wind direction and magnitude are known from Eqs. (9 and 10). Substituting Eqs. (9 and 10) into Eq. (5) and expanding yields the true airspeed

$$V_T^4 - \frac{P}{2}V_T^2 + \frac{2Q^2 - 2RQ + R^2}{8} = 0 \quad (11)$$

Equation (11) is a quadratic equation in  $V_T^2$ . An analytical solution is of course immediately available. Specifically

$$V_T = \sqrt{\frac{-b \pm \sqrt{b^2 - 4c}}{2}} \quad (12)$$

where

$$b = -P/2 \text{ and } c = (2Q^2 - 2RQ + R^2)/8$$

Additional credibility for the horseshoe heading method is provided by inflight measurement by Lewis at the National Test Pilot School using a trailing cone on a Merline III for comparison found excellent agreement with the horseshoe heading GPS method in determining position error corrections.

#### IV. Procedure

Fly a series of runs composed of three legs each at an increasing 90° heading from the previous leg as shown in Figure 1. Runs will be made at constant power settings (constant MP and RPM) at best power mixture in either the clean, flaps extended, gear extended or gear and flaps extended configuration.

*Students shall:*

1. Prior to flight, record aircraft tachometer, fuel quantity, altimeter and outside air temperature readings.
2. Determine sea level altimeter.
3. Determine aircraft weight.
4. Record IAS and GPS ground speeds for each of the three legs. Record altitude, fuel flow, fuel quantity, tach time, and OAT for each leg.
5. Record postflight aircraft tachometer, fuel quantity, altimeter and OAT readings.

#### V. Flight test report requirements

Calculate:

$W$  = aircraft test run weight

TAS = true airspeed

IAS = indicated airspeed

$IAS_w$  = IAS corrected to reference weight

$T$  = test run temperature

$p$  = test run pressure

$\rho$  = test run density

CAS = calibrated airspeed

Calculate and Plot:

$CAS_w$  = CAS corrected to reference weight

$\Delta P/q_{c_i}$  vs  $V_{i_w}$

$\Delta h_{pos}$ ,  $\Delta V_{pos}$  vs  $V_{i_w}$  at the test altitude

$\Delta V_{pos}$  vs  $V_{i_w}$  at 2,500 and 3,000 feet

Include a set of detailed sample calculations for one airspeed calibration run. Use any run you desire. For purposes of determining aircraft weight from the fuel quantity given by the fuel computer, average the weight at the beginning and the end of the run.